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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 :
F16L 13/00, B23P 1/02

A1

(11) International Publication Number: WO 91/0443

(43) International Publication Date: 4 April 1991 (04.04.9

(21) International Application Number: PCT/US90/05099

(22) International Filing Date: 10 September 1990 (10.09.90)

(30) Priority data:
406,665 13 September 1989 (13.09.89) US

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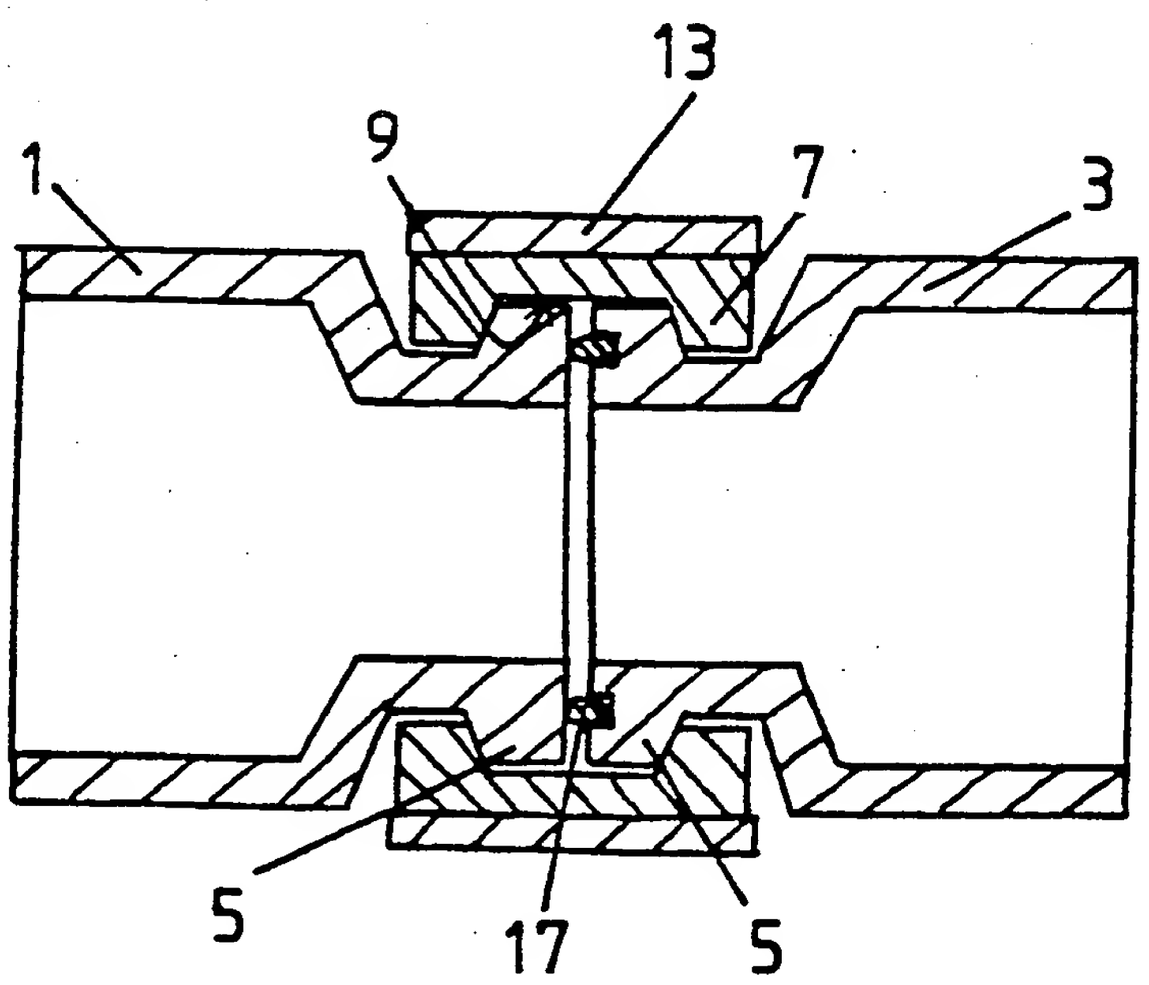
(81) Designated States: AT (European patent), BE (European patent), CA, CH (European patent), DE (European patent)*, DK (European patent), ES (European patent FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD OF FORMING A CONNECTION BETWEEN TWO OBJECTS SUCH AS TUBES USING A SHAPE MEMORY ALLOY COMPONENT



(57) Abstract

A method of forming a connection between two objects such as tubes (1, 3) using a shape memory alloy component (13). One of the objects bears a ridge and the other object bears a groove. One of the objects is positioned within the end of the other object and one or both of the objects is deformed radially as a result of recovery of the shape memory alloy component (13) so that the ridge and the groove engage one another.

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Method of forming a connection between two objects such as tubes using a shape memory alloy component

This invention relates to a method of forming a connection between at least two objects.

A connection may be made between objects by means of coupling which comprises a shape memory alloy component. Shape memory alloys exhibit a shape memory effect as a result of their ability to transform between martensitic and austenitic phases. The transformation may be caused by a change in temperature: for example, a shape memory alloy in the martensitic phase will begin to transform to the austenitic phase when its temperature increases to a temperature greater than A_s, and the transformation will be complete when the temperature is greater than A_f. The reverse transformation will begin when the temperature of the alloy decreased to a temperature less than M_s and will be complete when the temperature is less than M_f. The M_s, M_f, A_s and A_f temperatures of a shape memory alloy define the thermal transformation hysteresis loop of the alloy. An article formed from a shape memory alloy may be formed in a desired configuration while the alloy is in its austenitic phase. If the article is then cooled so that the alloy transforms to the martensitic phase, it can then be deformed so as to obtain a strain of up to about 8%. The strain imparted to the article is recovered when it is subsequently heated so

that it transforms back to the austenitic phase. Further information is available in the article by L. M. Schetky in Scientific American, Volume 241, pages 68 to 76 (1979) entitled Shape Memory Alloys.

US-4198081 discloses a radially shrinkable tubular coupling which has circumferentially extending teeth formed in its internal surface. Tubes to be coupled are positioned within the coupling which is then heated to cause it to shrink radially so that its teeth bite into the external surfaces of the tubes so as to grip the tubes. A fluid-tight seal is provided between the coupling and the tubes by the teeth as they bite into the surfaces of the tubes. The teeth also enhance the axial stress that can be withstood by the connection between the coupling and the tubes. Such couplings do however suffer from the disadvantage that the connection between the coupling and the tubes involves permanent deformation or scarring of the tubes. This can render it difficult to remake a connection between tubes using the disclosed coupling as can be required, for example, for the purposes of repair.

We have devised a method of forming a connection between two objects, one of which bears a groove and the other of which bears a ridge, the connection being made and achieving axial strength by engaging the ridge in the groove. Such engagement is brought about by recovery of a shape memory alloy component which may be one of the objects or a driver that is provided in addition to the objects to be connected.

In one aspect, the invention provides a method of forming a connection between at least two objects, a portion of at least one of the objects being hollow and capable of receiving a portion of the other object within it, the method comprising:

(a) positioning a portion of one of the objects within the hollow portion of the other object, one of the facing surfaces of the objects bearing a ridge and the other of the facing surfaces bearing a groove which is capable of receiving the ridge;

(b) positioning a radially heat-recoverable shape memory alloy driver with the overlapping portions of the objects in the direction of its recovery; and

(c) increasing the temperature of the driver above the A_s temperature of the alloy to cause the driver to recover so as to deform one of the objects and to cause the ridge and the groove to engage one another.

In another aspect, the invention provides a method of forming a connection between at least two objects, a portion of at least one of the objects being hollow and capable of receiving a portion of the other object within it, the method comprising:

(a) positioning a portion of one of the objects within the hollow end portion of the other object, one of the facing surfaces of the objects bearing a ridge

and the other of the facing surfaces bearing a groove which is capable of receiving the ridge, at least part of one of the objects being formed from a shape memory alloy and being radially heat-recoverable and having the other of the objects positioned in the direction of its recovery; and

(b) increasing the temperature of the shape memory alloy object above the A_S temperature of the alloy to cause the object to recover radially so that the ridge and the groove engage one another.

The method of the present invention has the advantage that a connection can be made between two objects having a high axial strength without deformation or scarring of either of the objects. Indeed, the axial force which the connection can withstand can be significantly greater than that of a connection made according to the teachings of US-4198081, since significantly greater engagement between the ridge and the groove is possible than in the case of teeth which bite into a surface. Furthermore, this allows a connection between the objects or to one of the objects to be remade with the same mechanical characteristics, as can be required, for example in the event of repair. In particular, the connection can be remade with a substantially equally effective seal and with substantially equal axial strength.

The objects which may be connected by the method of this invention may be solid, having the form of rods or

bars and having a hollow portion at one end to allow the connection to be made. For example the method may be used to connect electrical conductors such as bus bars to one another. The method may also be used to connect sections of a drive shaft, which may be hollow or solid; it has several advantages over connections formed by bolting flanges together, such as better vibrational characteristics due to a more uniform weight distribution along the length of the shaft, and therefore reducted bearing wear, a lower space requirement, and easier and quicker installation. The method finds particular application in the interconnection of hollow tubular objects such as pipes and tubes and, in particular, hollow housings. The hollow objects will generally have a circular cross-section, but this need not necessarily be the case.

The method may be used to connect objects formed from different materials. Indeed, it is an advantage of the present invention that connections may be made between materials whose characteristics are such that they cannot be connected by conventional techniques such as welding. For example, the method may be used to connect a polymeric object to a metal object, such as a fiber-reinforced polymer tube or shaft to a metal pump or drive unit.

One of the objects may bear two ridges or two grooves or a ridge and a groove on the surface which faces the other object. The method may then include the steps of forming connections between that object and two other

objects through respective ones of the ridges and/or grooves on the surface.

The groove may be cut into an otherwise uniform surface of an object, or it may be defined longitudinally by at least one circumferentially extending ridge which stands proud of the surface of the object. When there is just one such ridge, the groove will be open ended at one of its ends so that, in effect, the groove is equivalent to a ridge which engages another ridge on the other object. Such an arrangement is entirely satisfactory form some applications, particularly when the connection is only subjected to force in a single direction.

The groove in one of the objects may be capable of receiving ridges on two objects, and may be used to interconnect two objects, each of which bears a ridge which can be received within the groove.

The shape memory alloy object or driver may be shrinkable or expandable according to the requirements of a particular application. Preferably it is shrinkable and as positioned with the other object, to which the connection is to be made, radially within it.

A support may be provided to control the deformation of the objects when the shape memory alloy object or driver recovers. For example, when the shape memory alloy object or driver shrinks on recovery, the support will be positioned inside the object towards which the shape memory alloy object or driver shrinks.

The object towards which the shape memory alloy object recovers may be weakened to facilitate its deformation. For example it may be slotted longitudinally. This has the advantage that a greater amount of radial deformation is available elastically, which in turn allows a connection to the weakened object to be remade. This will not always be possible when the object is deformed plastically, although the object may be deformed plastically in some applictions, particularly when connections need not be remade easily. When the object is so weakened by providing slots or apertures in its wall, an additional seal may be required if a fluid-tight connection is desired.

The shape memory alloy will be selected according to the temperature to which the object or driver formed from it will be exposed before, during and after installation, and to the physical requirements placed on it when in use. The alloy may be based on copper, for example as disclosed in US-4144057 or US-4144104, or more preferably on nickel-titanium, for example as disclosed in US-3753700, US-4337090, US-4565589 or US-4770725. A preferred method of treatment of a nickel-titanium based shape memory alloy is disclosed in US-4740253. The subject matter disclosed in these documents is incorporated herein by these references to the documents.

The axially facing surfaces of the ridge or the groove or both may be inclined to the axis of the objects so that when the shape memory alloy object or driver reco-

vers, an axial force is applied between the objects. A method of applying an axial force in this way is disclosed in US patent application no. 07/335608. The subject matter disclosed in that document is incorporated herein by this reference to the document.

Preferably, the or each ridge is tapered inwardly towards its tip.

Preferably, the or each groove is tapered inwardly towards its base.

When a shape memory driver is used to make the connection, it may have the form of a hollow tubular band having a substantially uniform surface facing the direction in which it recovers. For example, if the driver is shrinkable, its internal surface will be uniform. Such a driver has the advantage that it is earsier, and therefore cheaper, to manufacture. Furthermore, when it is necessary to cut the driver in order to reenter the connection, only the driver need be discarded, the driver being relatively easy to manufacture when it does not have a ridge or a groove.

The connection may be such that a fluid-tight seal is formed between the objects. The seal may be provided between the coacting axially facing surfaces of the cooperating ridge and groove, for example as discussed in US patent application no. 07/335608 referred to above. Alternatively or in addition, a seal may be provided by positioning a quantity of resiliently

deformable material between the facing surfaces of the object to provide a seal between them. The material may be provided on axially facing surfaces of the ridge or the groove or both. The quantity of resiliently deformable material may be provided in the form of a gasket which may be located, for example, in a recess in one of the axially facing surfaces.

Brief description of the drawings:

Figure 1 is a longitudinal cross-section through a first embodiment of a connection between three objects;

Figure 2 is a longitudinal cross-section through a second embodiment of a connection between three objects;

Figure 3 is a longitudinal cross-section through a third embodiment of a connection between three objects; and

Figure 4 is a longitudinal cross-section through a chain of interconnected objects.

Description of preferred embodiments:

Figure 1 shows two tubular objects 1, 3 which are to be interconnected, each having a radially outwardly extending ridge 5 at its end. The ridges are tapered inwardly towards their tips.

The connection between the objects 1, 3 is made by means of a tubular object 7 having a groove 9 formed in its internal surface in which the ridges 5 can be received. The groove is tapered inwardly towards its base so that the coacting axially facing surfaces on the ridges and the groove respectively are inclined to the axis of the objects.

The connection is made by radially inward deformation of the grooved object 7 so that the groove 9 and the ridges 5 engage one another. The grooved object is deformed by means of a shape memory alloy driver 13. The driver is in the form of a tubular band having a substantially uniform internal surface.

The driver is formed from a nickel-titanium based shape memory alloy, such as a nickel-titanium-iron alloy as disclosed in US-3753700 or a nickel-titanium-niobium alloy as disclosed in US-4770725. The alloy is processed so that the driver can be made to shrink radially by the application of heat.

A gasket 17 formed from a resiliently deformable material is provided between the objects 1, 3 is a recess in one of the objects. As the grooved object 7 is deformed inwardly by the driver 13 as it recovers, the objects 1, 3 are forced towards one another as a result of the configuration of the coacting axially facing surfaces of the groove 9 and the ridges 5. As a result, the gasket 17 is compressed between the objects 1,3, forming a seal between them.

Figure 2 shows two tubular objects 21, 23 which are to be interconnected, each having a radially inwardly extending ridge 25, at its end.

The connection between the objects 21, 23 is made by means of a tubular object 27 having a pair of grooves 29 formed in its external surface in which the ridges 25 can be received.

The connection is made by deformation of the objects 21, 23 inwardly so that the ridges 25 are received in the grooves 29 in the grooved object 27. The objects 21, 23 are deformed by means of a shape memory alloy driver 33. The driver is in the form of a tubular band having a substantially uniform internal surface.

Gaskets 37 are provided in recesses in the grooved object 27, between the grooved object and each of the objects 21, 23 to be connected.

Figure 3 shows two tubular objects 51, 53 which are to be interconnected, each having a radially inwardly extending ridge 55 at its end.

The connection between the objects is made by means of a hollow shape memory alloy object 57 having a groove 59 formed in its internal surface in which the ridges 55 can be received.

The connection is made by increasing the temperature of the grooved object 57 above the A_s temperature of the

alloy so that the object shrinks radially, so that the groove 59 receives the ridges 55 within it.

A support ring 61 is provided inside the objects 51, 53 to support them against inward deformation under the recovery force exerted by the grooved object 57 when it recovers.

Figure 4 shows three indentical objects 71, 72, 73 each having an outwardly facting ridge 74 at one end and an inwardly facing groove 75 at its other end. Each groove 75 is defined at one axial end by an inwardly facing ridge 76, and is open at its other end.

The objects are connected by positioning them with the ridged end portion of one object within the grooved end portion of the adjacent object, and with a shape memory alloy driver 77 surrounding the overlapping end portions of objects. The temperature of the driver is then increased to cause it to shrink radially, so as to deform the grooved end portion of each object inwardly until it engages the ridged end portion of the adjacent object.

The objects 71, 72, 73 may be sections of a drive shaft. Preferably the materials of the sections will be the same as one another, but for some applications, it may be preferable for the materials to differ.

What is claimed is:

1. A method of forming a connection between at least two objects, a portion of at least one of the objects being hollow and capable of receiving a portion of the other object within it, the method comprising:

(a) positioning a portion of one of the objects within the hollow portion of the other object, one of the facing surfaces of the objects bearing a ridge and the other of the facing surfaces bearing a groove which is capable of receiving the ridge;

(b) positioning a radially heat-recoverable shape memory alloy driver with the overlapping portions of the objects in the direction of its recovery; and

(c) increasing the temperature of the driver above the A_S temperature of the alloy to cause the driver to recover so as to deform one of the objects and to cause the ridge and the groove to engage one another.

2. A method as claimed in claim 1, in which the facing surface of one of the objects bears two ridges or two grooves or a ridge and a groove, and the method includes the steps of forming connections between that object and two objects through respective ones of the ridges and/or grooves on the surface.

3. A method as claimed in claim 2, in which the objects which are connected to the object bearing two ridges and/or grooves are hollow tubular objects.

4. A method as claimed in claim 1, in which the driver is radially heat-shrinkable.

5. A method as claimed in claim 1, in which the driver has the form of a hollow tubular band having a substantially uniform surface facing the direction in which it recovers.

6. A method as claimed in claim 1, in which the ridge is tapered inwardly towards its tip.

7. A method as claimed in claim 1, in which the groove is tapered inwardly towards its base.

8. A method as claimed in claim 1, which includes the step of providing a quantity of a deformable material between the objects to provide a seal between them.

9. A method as claimed in claim 8, in which the quantity of resiliently deformable material has the form of a gasket.

10. A method as claimed in claim 1, in which the object positioned between the driver and the other object is weakened to facilitate its radial deformation by the driver when it recovers.

11. A method as claimed in claim 10, in which the weakened object has longitudinal slots extending from one end.

12. A method as claimed in claim 1, in which the facing surface of one of the objects bears a groove with can receive two ridges, one on each of two other objects, and the method includes the steps of forming connections between the grooved object and the two objects which bear the ridges by positioning the ridges so that they are engaged by the groove when the driver recovers.

13. A method as claimed in claim 1, in which the materials of the two objects are different from one another.

14. A method as claimed in claim 13, in which one of the objects is formed from a metallic material, and the other of the objects is formed from a polymeric material.

15. A method as claimed in claim 1, in which the objects are sections of a drive shaft.

16. A method of forming a connection between at least two objects, a portion of at least one of the objects being hollow and capable of receiving a portion of the other object within it, the method comprising:

(a) positioning a portion of one of the objects within the hollow end portion of the other object, one of the facing surfaces of the objects bearing a ridge and the other of the facing surfaces bearing a groove which is capable of receiving the ridge, at least part of one of the objects being formed from a shape memory alloy and being radially heat-recoverable and having the other of the objects positioned in the direction of its recovery; and

(b) increasing the temperature of the shape memory alloy object above the A_S temperature of the alloy to cause the object to recover radially so that the ridge and the groove engage one another.

17. A method as claimed in claim 16, in which the facing surface of the shape memory alloy object bears two ridges or two grooves or a ridge and a groove, and the method includes the steps of forming connections between the shape memory alloy object and two objects through respective ones of the ridges and/or grooves on the surface.

18. A method as claimed in claim 17, in which the objects which are connected to the shape memory alloy object are hollow tubular objects.

19. A method as claimed in claim 17, which includes the step of positioning a support so as to bridge the

ends of the objects which are connected by the shape memory alloy object and to support those objects when the shape memory alloy object recovers.

20. A method as claimed in claim 16, in which the facing surface of the shape memory alloy object bears a groove which can receive two ridges, one on each of two other objects, and the method includes the steps of forming connections between the grooved object and the two objects which bear the ridges by positioning the ridges so that they are engaged by the groove when the shape memory alloy object recovers.

21. A method as claimed in claim 16, in which the shape memory alloy object is radially heat-shrinkable.

22. A method as claimed in claim 16, in which the ridge is tapered inwardly towards its tip.

23. A method as claimed in claim 16, in which the groove is tapered inwardly towards its base.

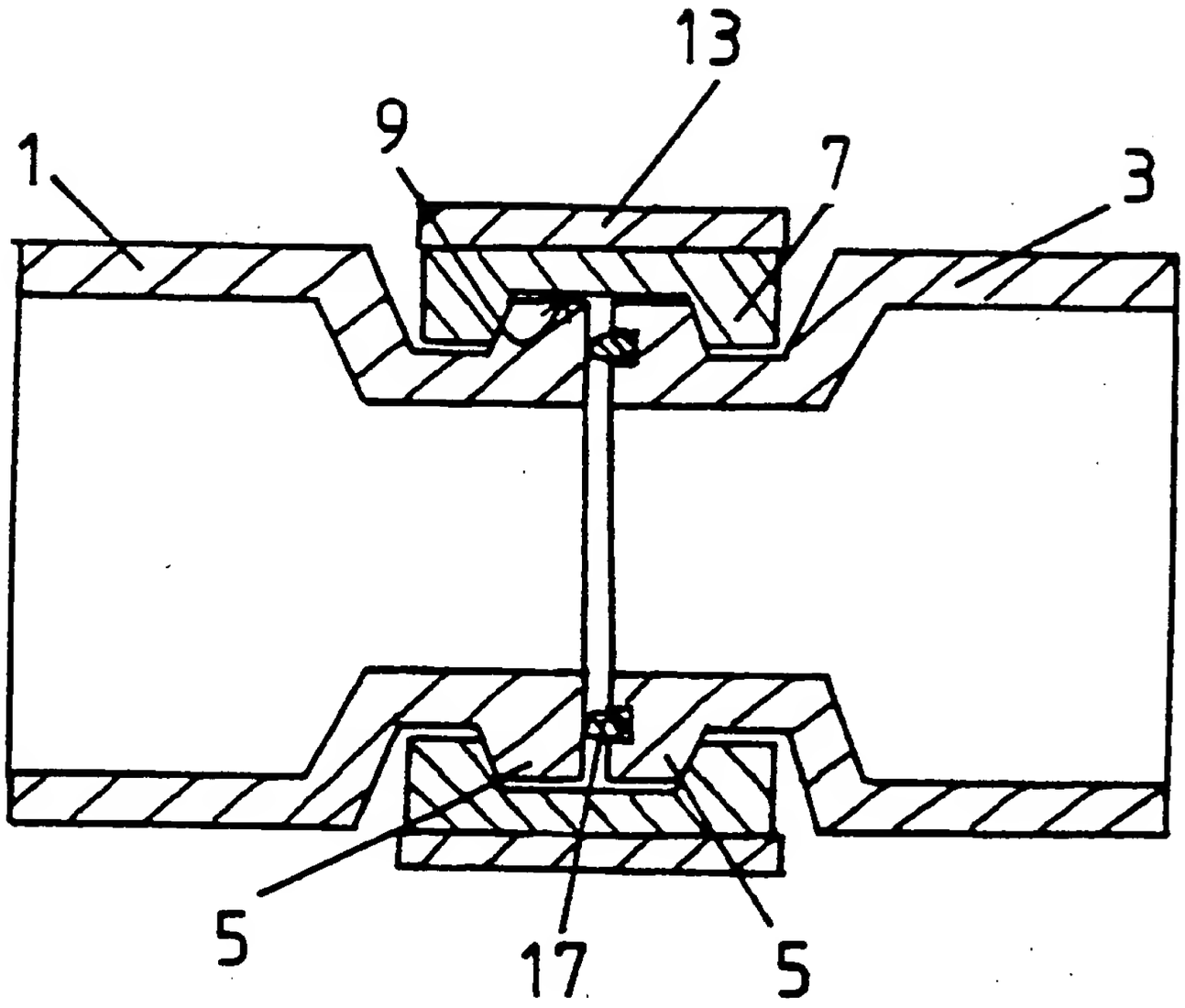

FIG 1

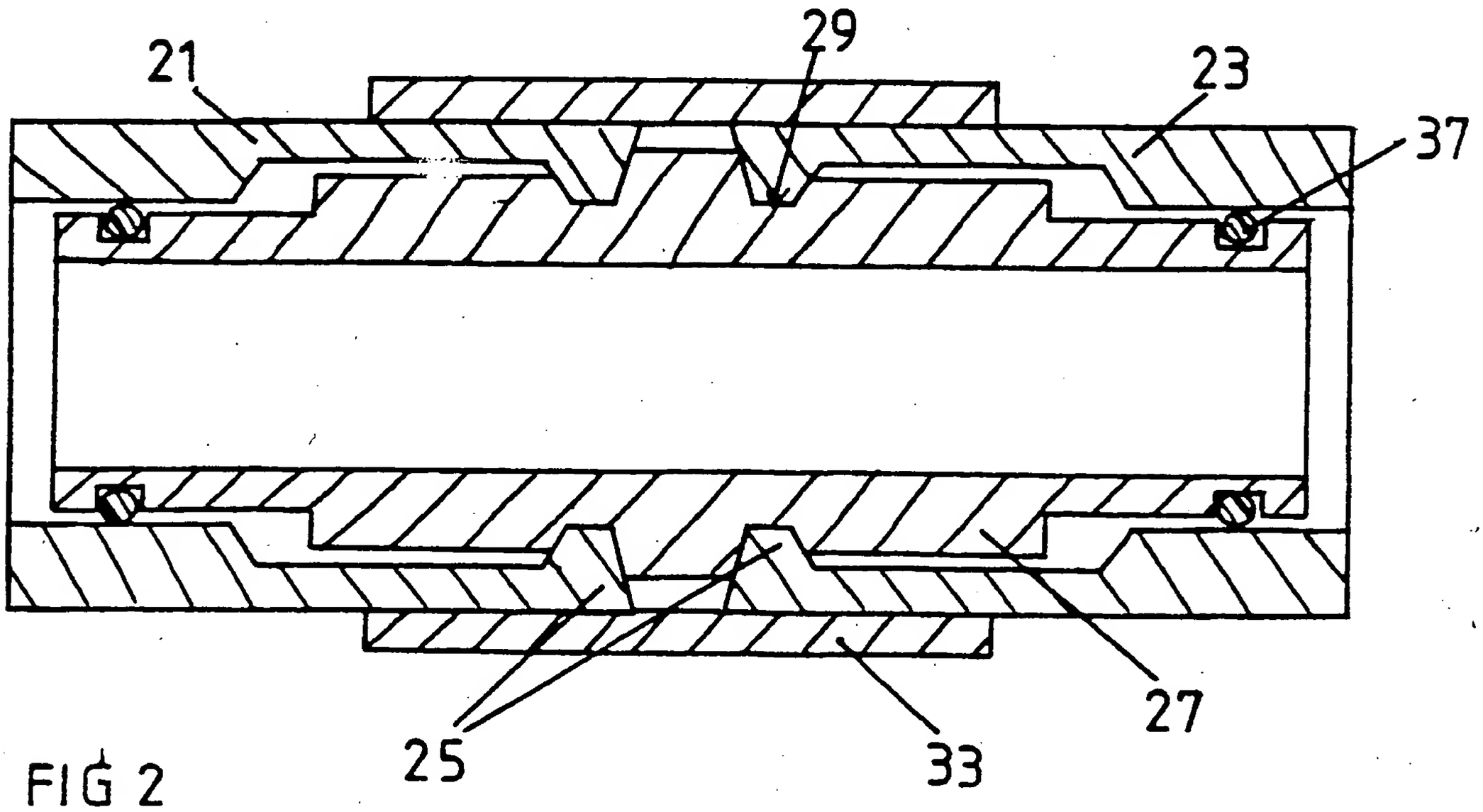

FIG 2

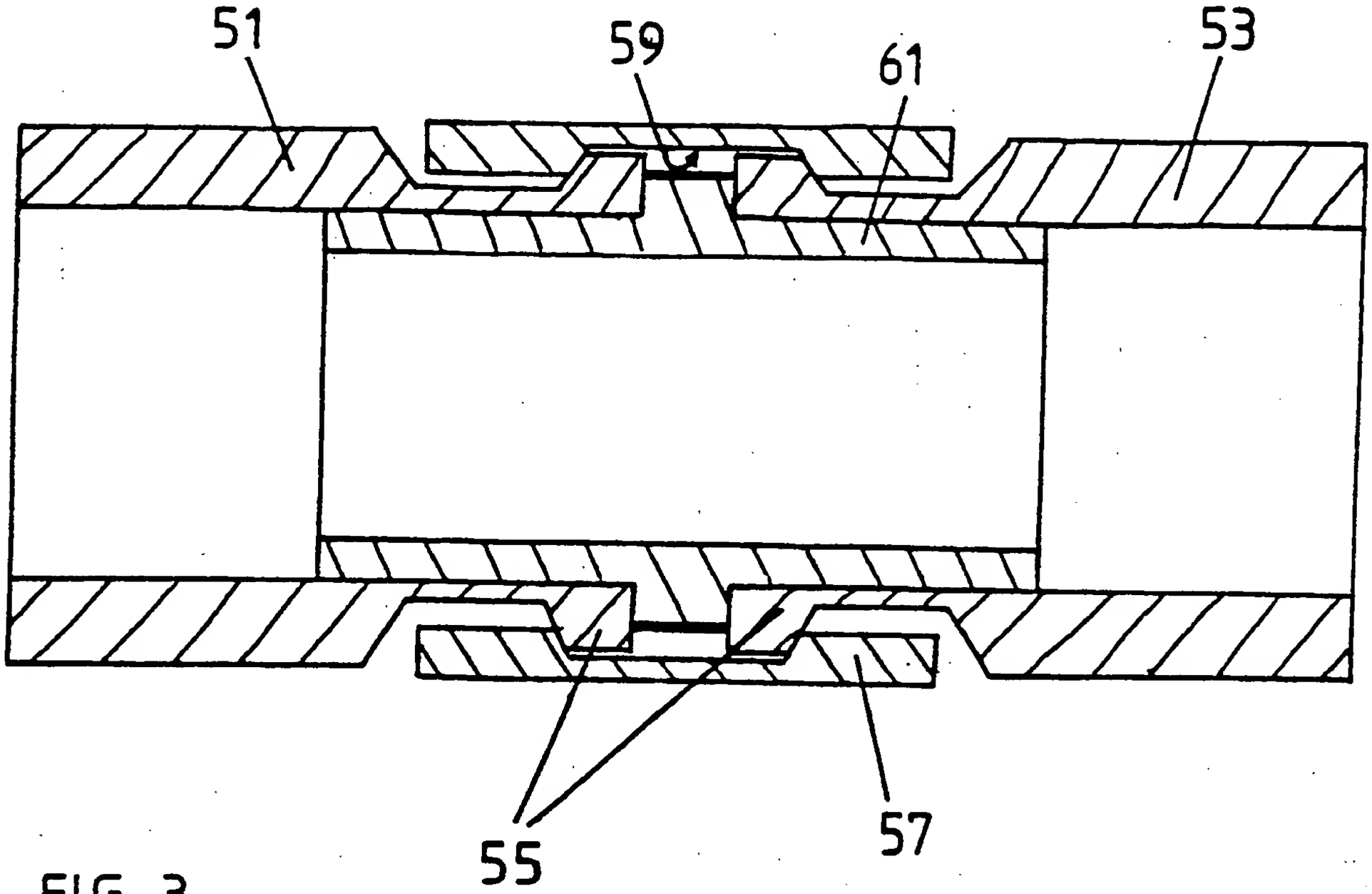

FIG 3

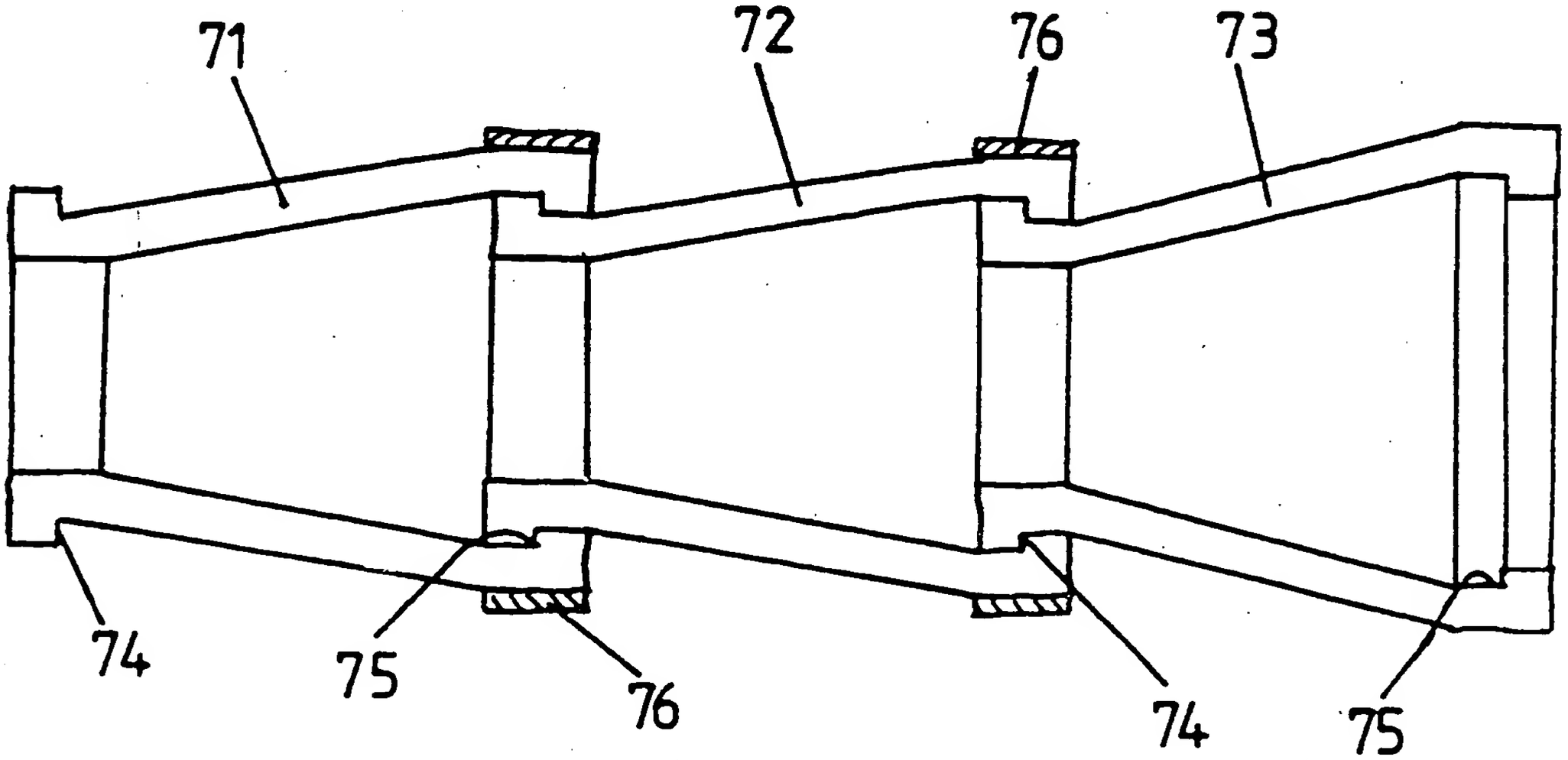

FIG 4

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/05099

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F16L13/00 ; B23P1/02

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	F16L ; B23P ; F16D

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	EP,A,302618 (BTR INDUSTRIES LTD.) 08 February 1989 see abstract; figures 3-5	1, 2, 3, 4, 5, 8, 9
A	FR,A,2547631 (COMMISSARIAT A L'ENERGIE ATOMIQUE) 21 December 1984 see page 8, line 20 - page 9, line 14; figure 3b	6, 7
A	FR,A,2306785 (RAYCHEM CORP.) 05 November 1976 see figures 2a, b	10, 11
A	US,A,4198081 (HARRISON ET AL.) 15 April 1980 see abstract; figures (cited in the application)	1, 3, 4, 16, 18, 21
A	DE,A,3007307 (BBC AG BROWN, BOVERIE & CIE.) 23 July 1981 see claim 1; figures	1, 4, 5, 15, 16, 21

° Special categories of cited documents : [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
17 DECEMBER 1990	22. 01. 91
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	BARTSCH A.W.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. PCT/US 90/05099

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on
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